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CDHC Workshop Proceedings:

Guidance for an Epidemiological Strategy and Establishing a Disease Surveillance Network for Caribbean *Acropora palmata*

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St. Matthew's University
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About This Document

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About the CDHC

In response to the global decline in coral reefs, the U.S. Coral Reef Task Force's National Action Plan to Conserve Coral Reefs called for the creation of a *Coral Disease and Health Consortium (CDHC)*. The CDHC organizes and coordinates the scientific resources of the U.S. and its territories to meet the challenge of globally declining coral reefs. Its mission is to preserve and protect the health of coral reef ecosystems through an understanding of the effects of natural and anthropogenic stressors on reef-building communities. The CDHC serves to unify the coral health and disease research community, identify research priorities, and encourage a new generation of coral researchers through education and outreach. The biomedical perspective and innovative technologies developed from Consortium efforts is envisioned to give scientists, resource managers, and industry new tools to identify and alleviate hidden stresses before they become environmental health crises. Currently over 125 national & international partners, including federal agencies, NOAA, DOI, EPA, along with academia, non-profit and industry, contribute their time and expertise to the CDHC, while organizational infrastructure is supported by the congressionally funded NOAA Coral Reef Conservation Program.

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CDHC Workshop Report:

Guidance for an Epidemiological Strategy and Establishing a Disease Surveillance Network for Caribbean Acropora palmata

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EXECUTIVE SUMMARY

Acropora palmata was listed as threatened under the Endangered Species Act in May 2006 (71 FR 26852). In 2012, the National Marine Fisheries Service proposed the reclassification of *A. palmata* (77 FR 73219) as endangered, but determined in 2014, that they would remain listed as threatened under the ESA (79 FR 53852). This coral is present only in the Caribbean where its existence is threatened by infectious pathogens, pollution, and human activities. There is a critical need to conserve remaining stocks of corals, but the status of this species is unknown in many regions in the Caribbean because the capacity to assess their condition and monitor reefs is lacking. This is particularly challenging in many Caribbean locations (e.g., small island countries). With limited financial and personnel resources, these managers lack access to a coordinated network of collaborators. The goal of this workshop was to provide methods that can assist coral reef managers, particularly those with limited resources, to assess and manage the health of their respective coral populations with a focus on *A. palmata* as a sentinel species. Specific aims of this workshop were as follows:

1) Develop survey methods based on the sound principles and theories of epidemiology that can:
    a. Provide demographic data directly comparable across regions.
    b. Be simple enough to apply for managers with limited means.
    c. Have sufficient sensitivity to detect adverse changes on reefs before it is too late to intervene.
2) Develop a means to analyze survey data to detect status and trends with the overarching goal to:
    a. Detect and report declines in populations or recruitment or increase in mortality on a real-time basis.
    b. Define trigger mechanisms that would merit the recruitment of outside experts to help investigate potential causes of unusual disease outbreaks or increases in mortality.
3) Ensure that surveillance design and analyses are sound and appropriate for island biogeographic settings.
4) Design the surveillance methodology and networks targeted to small Marine Protected Areas with limited resources.
5) Develop a hierarchical structure, using the U.S. Centers for Disease Control and the World Health Organization as models, to develop an implementation strategy for methods in which surveillance is conducted and data analyzed, to detect anomalies. Resource managers are supplied inexpensive techniques to diagnose the change and then a means of accessing expertise when situations demand more specialized investigations.
6) Identify new methods or techniques from the available expertise to incorporate into the overall guidance document.

The format was a working meeting with twelve recognized experts that were tasked with developing a guidance document on disease surveillance and response. Each participant played a vital role in developing the methodology supporting this guidance document; their collective expertise included epidemiology, veterinary medicine, coral physiology, watershed characterization and resource management. The workshop was not a forum for presentations or discussion of policy issues.

I. Introduction

The health and continued existence of coral reef ecosystems are threatened by an increasing array of environmental and anthropogenic risk factors. Though the specific causes can vary from one location to another, coral health is being undermined by pollution, climate change, habitat destruction and over-exploitation of marine resources. These and other environmental and anthropogenic factors result in increasing disease manifestations, mortality and reproductive failure across coral populations. The unprecedented loss and continued trajectory of failure of one of the most complex, biologically diverse, and economically valuable habitats on earth was recognized by the U.S. Federal government in 1998. In an effort to form a cohesive national strategy to conserve and protect these ecosystems, President William Jefferson Clinton issued Executive Order 13089 on June 11, 1998 that established the United States Coral Reef Taskforce (CRTF). The U.S. CRTF efforts resulted in an action plan for coral reef conservation efforts. In addition, the U.S. Congress passed legislation on the Coral Reef Conservation Act of 2000 for implementation and appropriations. A decision for reauthorization of the Coral Reef Conservation Act is currently before the U. S. Congress.

Though these focused efforts of the U.S. have been in place for over 15 years, reports internationally continue to forecast coral reef loss with only a few localized examples emerging of recovery or healthy reefs. Caribbean reefs have suffered particularly significant loss. In 2006, two species, elkhorn (*Acropora palmata*) and staghorn (*A. cervicornis*) corals were listed as threatened under the Endangered Species Act (ESA) of 1973, as amended on May 9, 2006 (71 FR 26852) in response to a 2004 listing petition from The Center for Biological Diversity. In 2012 their status was reviewed by the National Marine Fisheries Service and it was determined their status would remain as threatened. Because of its status, *Acropora palmata* was chosen as the subject of this workshop with the goal to initiate surveillance efforts.

The genus *Acropora* is the most abundant and species-rich group of corals in the world. However *A. palmata* and *A. cervicornis* are two of only three acroporids that are found in the Atlantic/Caribbean, typically in shallow water. The third acroporid is a hybrid of elkhorn and staghorn corals, known as fused-staghorn coral *(A. prolifera)*. Historically elkhorn and staghorn corals were the dominant framework-building species on Atlantic/Caribbean coral reefs, and their high growth rates have allowed them to adapt to sea level changes. Both species, however, underwent precipitous declines in abundance in the early 1980s throughout their range, and this decline has continued (Aronson & Precht 2001). Although quantitative data on former distribution and abundance are scarce, in the few locations where quantitative data are available (e.g., Florida Keys, Dry Tortugas, Jamaica, and the U.S. Virgin Islands), declines in abundance are estimated at greater than 97 percent (Porter *et al.* 2002). Data suggests that the decline in Atlantic *Acropora* abundance is primarily the result of disease (as a proximal cause of death); however, temperature-induced bleaching, human activities (e.g., construction, polluted run-off, degraded water quality) and physical damage (e.g., hurricanes, anchoring) have also been implicated. With exposures to these adverse conditions and the effects of disease, there have been significant population losses resulting in reductions in the ability of coral to successfully reproduce, both sexually and asexually (Quinn & Kojis 2006; Federal Register 2008).

To insure the species do not decline further, actions are needed to determine the causal and mechanistic aspects of these threats to both species. ***(Biological Status Review 2005)***

The challenge is to move away from a triage approach in dealing with coral reef decline (in this particular case, Caribbean *Acropora*), to a position of being able to identify and quantify factors driving these systems to failure and put into place practices to recover the losses. This requires being able to detect change in coral health at the individual and population level before visible changes manifest at the community and ecosystem levels. Detecting change however requires establishing a baseline of coral health status at the beginning of a surveillance program, and then using standardized and accepted diagnostic methodologies to track changes in coral health.

Epidemiology is the study of disease in populations and of the factors that determine its occurrence ***(Thrusfield 2007)***

The principles and methodologies of epidemiology provide a systematic approach to identify and quantify risk factors that impact coral health (e.g., infectious agents, toxicants, unfavorable environmental conditions) and quantify their relative contribution.

- *Phase I* involves characterizing populations at risk followed by detecting changes in morbidity, survivorship and/or recruitment at a level of sensitivity that permits intervention;
- *Phase II* involves identifying the most probable factors that could cause morbidity or declines in survivorship and/or recruitment;
- *Phase III* demonstrates the etiology or probable cause for morbidity and mortality;
- *Phase IV* translates this information into management actions and assesses their effectiveness in slowing declines in survivorship and/or recruitment.

Surveillance is gathering, recording and analysis of data, and dissemination of information to interested parties so that action can be taken to control disease ***(Thrusfield 2007)***

Though this document focuses on establishing a surveillance program for *Acropora palmata,* this methodology is applicable to any species of interest and is the first step toward implementing an Epidemiological Strategy. The objectives of surveillance are three-fold:

1. **Collect baseline data for the population at risk**. In order to detect a change, you need to know the estimated numbers of animals involved, their distribution, recruitment parameters, and background levels of morbidity and mortality.
2. **Determine relevant health parameters and appropriate trigger points** (i.e., the degree of change in a given parameter) that merit implementation of Phase II (further investigation of a perceived change). This may include documentation of new lesions not previously recorded, or documenting an X% decline in recruitment or Y% increase in mortality in recruitment over Z years.
3. **Conduct surveillance for particular lesions and triage (prioritize) which lesions are most important**. In the case of *A. palmata*, tissue loss, white syndrome and bleaching are priority lesions during surveillance activities because they can kill rapidly and have been documented in the past to lead to significant decreases in coral cover. However during surveillance monitoring all abnormal conditions should be recorded.

II. Epidemiological Strategy

PHASE I : SURVEILLANCE - IS CHANGE OCCURRING ON THE REEF?

1. Selecting Study Sites and Collecting Baseline Data

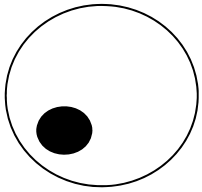
When initiating a surveillance program it is important to first define the species and populations of interest and their geographic location. Gathering historical information for the site and species (mortality rate, recruitment rate, gross lesions, watershed assessments; hydrology) will assist in an assessment and should be obtained where available. Google Earth is a useful tool to define the geographic context and contiguity of the populations of concern and to identify potential risk factors (e.g., aerial views can show land use patterns; runoff plumes). Sentinel colonies should be tagged (depending on jurisdiction, tagging is likely to be in adjacent substrate rather than on the colony), GPS mapped and an underwater map created to assist in locating colonies for repeated observations. The workshop members recommended two key factors to assess health in populations of concern: measures of change in morbidity and change in recruitment. To detect these changes, appropriate sites must be selected, and specific baseline data must be collected for each site. Consider proceeding as follows:

a) Identify the species and populations – in this case, *A. palmata* in defined reef localities.
b) Identify geographic regions with *A. palmata* at both local and Caribbean-wide levels.
c) Within each geographic region or jurisdiction, determine the areas with the largest aggregations or largest coverage of *A. palmata*. These should be the priority regions for surveillance because the priority objective is to save what is remaining, particularly given that resources are limited.
d) Establish standardized methods to survey demographics of these particular areas that are appropriate for the area, as different reef types may require different methods (e.g., dense thickets vs low density patches). The objective is to be consistent in methodology

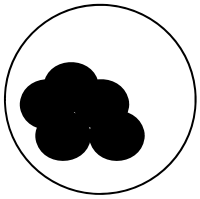
and as much as possible coordinate the specific method selected with other groups conducting surveillance in similar reef types. Many print and online resources are available describing methods for surveying corals, or the CDHC may be contacted for help with locating an expert. Characteristics to quantify include the number and size of colonies (for quantifying recruitment), percent cover, substrate characteristics, lesion number and size, and percent live/dead tissue. Belt transects are a convenient and effective method of quantifying colonies. This method consists of stretching a measuring tape 25-50 m in length and quantifying numbers and sizes of colonies within a 0.5-2 m swath on either side of the tape (this may be prohibited with endangered species, check with permitting officials). To track individual colonies, tagging can be done with non-corrosive materials (e.g., cable ties and plastic cattle tags). For *A. palmata*, placing the tag on adjacent substrate is preferred to reduce the risk of damage to the colony. The point intercept method can be used to quantify/classify the substrate in the same area—this consists of recording the nature of the substrate at regular points (i.e., every 10 cm) directly beneath the tape (e.g., Woodley *et al*. 2008 for protocol)

2. Detecting and Quantifying Changes in Morbidity

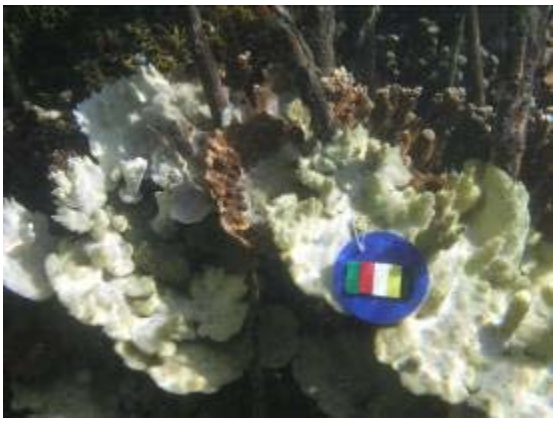
Morbidity can be assessed in terms of living tissue on the colony, and it is therefore important to select colonies for surveillance that have some living tissue (e.g., at time point zero, mortality = zero) (Fig. 1). *Acropora palmata* populations can occur in densities that range from sparse with colonies found meters apart to dense thickets where individual colonies are difficult to distinguish. In some instances, patch reefs have very low *A. palmata* density making it logistically possible to sample all colonies within an area of reef. This approach is preferred in cases with low species density.

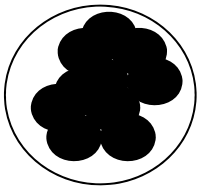


Grade 1: 0-25%
Dead Tissue



Grade 2: 25- 50%
Dead Tissue





Grade 3: 75% +
Dead Tissue

Figure 1 Example of scheme to grade tissue loss on colonies for assessing individual colony condition. In each frame an example photograph of tissue loss is provided and accompanied with a graphic that denotes live tissue (white circle) and dead tissue (black dots). Each pair is given a value based on the estimated percent of dead tissue. *Photos by Dr. Thierry Work.*

In cases with dense networks or thickets of *A. palmata* (such that density does not sufficiently allow sampling of entire reef), the exact number of colonies will depend on the size of the thicket. A reasonable sampling per strata for dense thickets in Phase I would be 10 colonies.

RECOMMENDATIONS for INDICATORS: Once populations of concern are identified, select a sentinel coral or select group of sentinel corals (e.g., 5 colonies) to monitor for change. A minimum monitoring frequency of once per year is suggested. Triggers indicating a move to Phase II can be based on a simple morbidity and recruitment chart (see below).

3. Detecting and Qualifying Changes in Recruitment

Recruitment is measured at a predetermined frequency, with once per year recommended.

There are two types of recruitment with *A. palmata*—fragmentation and larval settlement. Both should be recorded, and the specific type should be noted. If a colony is fragmented, this should be photo-documented and the percent of fragments that form new colonies should be recorded. Recruitment due to sexual reproduction and settlement of coral larvae is typically documented by recording the number of new recruits (colonies less than 0.5 cm in diameter) and by quantifying recent recruits according to size class (e.g. 1-10 cm, 11-20 cm, etc). Tagging, measuring and/or photo-documenting recruits over time can be used to assess recruit survival.

Belt transect surveys are a simple and effective approach for quantifying recruitment and determining size class distribution. Sites suitable for larval recruitment typically consist of rubble or other solid substrate with coralline algae. Unsuitable sites are those with fleshy micro or macro algae, and/or where the bottom is composed of soft sediment such as sand or silt. The first step in performing a survey is to choose a location that is suitable for larval recruitment and then as random as possible choose a location for the transect, while keeping the entire transect line within a suitable area. New *A. palmata* recruits (colonies less than 0.5 cm in diameter) are then quantified using at least three belt-transects of length suitable to the area of interest (e.g., 20 m, 30 m, 40 m, etc.). Members of this workshop recommended a minimum transect length of 20 meters and counting/measuring recruits within a 1 meter wide band along each transect. Larger colonies along the transects are quantified according to size class (e.g. 1-10 cm, 11-20 cm diameter, etc.). Colonies are only counted/measured if at least half of the entire colony falls within the 1 meter band.

4. Have changes occurred on the reef in terms of morbidity and/or recruitment and what is the nature of the change?

To determine if change is occurring on the reef a simple chart can be constructed that compares morbidity/mortality, recruitment and size class distribution, illustrating which parameters are showing positive or negative changes (Table 1). Any increase in morbidity/mortality or decrease in recruitment is considered a negative change, and depending on the severity (rate of change) or trigger thresholds (see below) may warrant Phase II investigation to identify potential risk factors. If both morbidity and recruitment are increasing, the population change might be considered “neutral”, but if the increased morbidity is severe/rapid it still warrants Phase II investigation. The worst-case scenario is when morbidity/mortality is increasing and recruitment is decreasing, indicating that the population is experiencing a severe negative change warranting rapid Phase II analysis and intervention.

In practice, it is important to recognize that these metrics wax and wane over time and have their own inherent fluctuations. Therefore, it is important to establish reasonable triggers depending on the data and specific situation. Hypothetically, a reasonable trigger could be

recruitment declines over at least three survey points or if a major (e.g., 80%) drop in recruitment is detected. For mortality measures in Phase I, lesions will be documented, therefore it is important to establish background levels of mortality in a given location. An appropriate trigger in this case may be an "outbreak" situation of new lesions where high prevalence occurs or an existing lesion increases from one survey to the next by 50% or more. Alternatively, for low-grade chronic lesions, consistent increases in tissue loss over three consecutive survey points can serve as a valid trigger to move to Phase II. If a negative change is detected and the change is deemed severe based on rate of change and/or trigger points being reached, begin Phase II to identify risk factors. If no negative changes are detected, continue with regular Phase I surveillance.

Table 1 Morbidity and recruitment chart used to assist managers in determining if changes are occurring and the relative severity of the changes (i.e., increasing morbidity with decreasing recruitment, as shown in the example below, is a worst-case scenario). Note that any negative change might warrant Phase II investigation, depending on the severity of the change.

	Negative Change	Positive Change	Comments
Morbidity/Mortality	--		53% increase in white patches
New recruitment	--		25% decrease in recruitment
Size class 1-10 cm	--		25% decrease in 1-10 cm corals
Size class 11-20 cm	N	N	Neutral- no change
Overall Assessment- Severe situation; increased morbidity with decreased recruitment—immediate Phase II investigation; decrease in 1-10 cm corals potentially indicates mortality among new recruits			

PHASE II – IDENTIFYING POSSIBLE RISK FACTORS - IF CHANGE IS DETECTED, WHAT ARE THE POTENTIAL CAUSES OF THE CHANGE?

As long as the coral population is stable or showing positive changes then Phase I monitoring (surveillance) should continue. Once any adverse change (e.g., reduction in recruitment or increase in morbidity) is identified in the survey population, Phase II should begin. Phase II moves from just surveillance into the next phase of the *Epidemiological Strategy* which is building a case for causation. Phase II is a more in-depth and targeted data collection effort to create a list of the most likely causative agents and what their impacts might be, also called a causal web.

1. Formulating a Causal Web

The causes of coral diseases are most often multifactorial and difficult to identify without extensive research. Some pathological conditions have many direct and indirect causes that represent a number of different pathways, with direct and indirect risk factors interplaying and culminating in a disease state. In Phase II of an epidemiological investigation, potential causative agents are identified and their interactions (or causative paths) developed into a Causation Web (Fig. 2) which illustrates the hypothesized relationships between direct and indirect risk factors. From these causal hypotheses, indicators of the risk factors are identified and measurements are made to determine which potential causative agents are likely the most important contributors to the problem. These risk factors and the resulting causal web should be developed at a local level (e.g., individual reef, watershed or embayment) to provide the most refined picture of the possible causal factors and their linkages. This will more effectively direct the investigation and diagnostic assays for identifying actual causes of the documented change and initiate intervention with the most appropriate management actions.

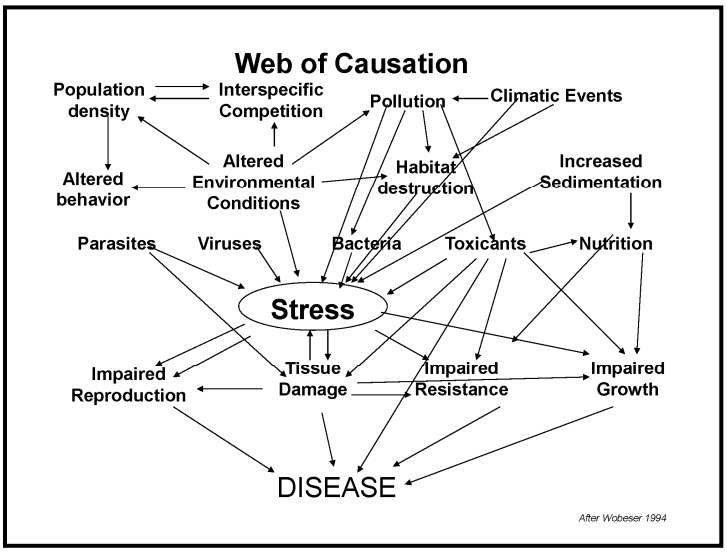


Figure 2 Web of Causation illustrating possible risk factors and their interactions. *Diagram by Dr. Cheryl Woodley*

The next step is to build a Conceptual Model (e.g. Fig. 3) showing relationships between the possible causal factors. First, the biological impairment that was detected during Phase I monitoring is defined. It is important to describe the impairment in specific terms and biological measures that are unambiguous, distinctive, relevant, informative, clear and unique to the specific case. The second step is to develop a list of candidate causes. These must be potentially sufficient to cause the impairment and may include several causes

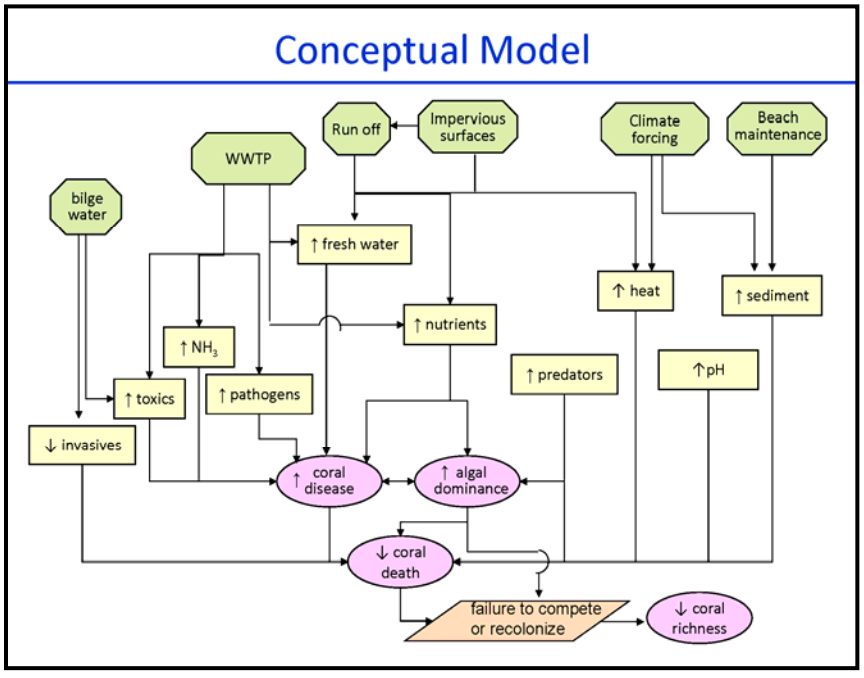


Figure 3 Example of a Conceptual Model consisting or candidate causes with known or suspected sources (Note: WWTP—Waste water treatment plant). *Diagram provided by Dr. Susan Cormier.*

that act together (additively or synergistically). This list may also identify known or suspected sources. To develop the list: a) make a map of area of affected coral colonies, the general and specific location (e.g., Fig. 4) highlighting proximities of possible sources, topology, land-water interfaces and other hydrographic, climatological or oceanographic features; b) gather existing information on potential sources, stressors and exposures potentially affecting the location; and develop causal web and conceptual model (Figs. 2 & 3).

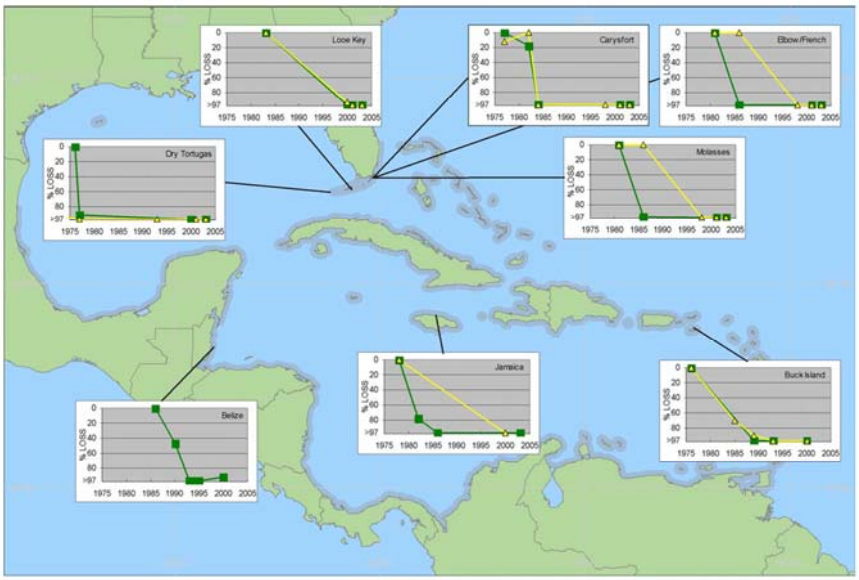


Figure 4 Percent loss of *Acropora cervicornis* (green squares) and *A. palmata* (yellow triangles) throughout the Caribbean for all locations (n=8) where quantitative trend data exist. (*Acropora* Biological Review Team (2005).

An ecological risk/threat assessment is one way of determining whether a candidate causal agent of a pathology is both relevant and probable.

2. Examples of Stressors and Indicators to Consider when Developing a Causal Web

Eutrophication. Nutrient input can be an important stressor leading to increases in algal overgrowth, decreases in light availability to corals, and increases in potential pathogens being introduced to the reef. An indicator of an increase in nutrient input is an increase in fleshy algal growth. If nutrients are perceived as a potential risk factor in the area, high growth rates of certain boring sponges can be assessed as an indicator of high nutrient input. *Cliona* sponges are ubiquitous on tropical reefs. *Cliona caribbaea* are co-located with Caribbean *Acropora*, and excellent indicators of water quality (Fig. 5). Their expansion rates in high quality reef waters are approximately 4 cm/year; rates exceeding this nominal level are indicative of poor water quality and specifically eutrophication (see Acker and Risk 1985).

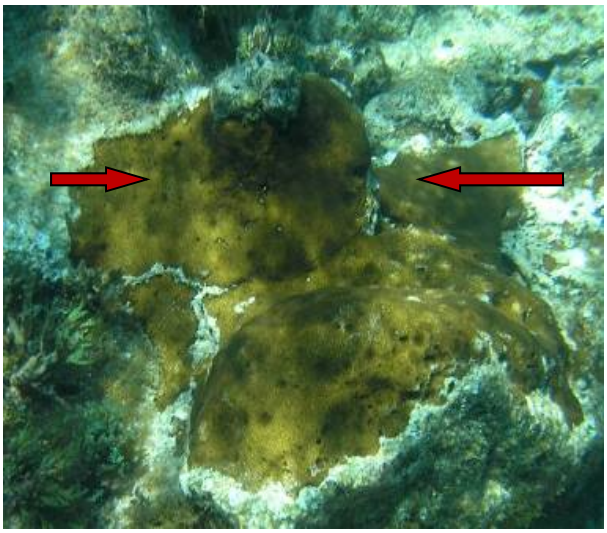


Figure 5 *Cliona caribbaea* (aka: *C. viridis, C. langae, C. orientalis*) a ubiquitous brown sponge found on coral reefs (red arrows). *Photo courtesy of Dr. Mike Risk.*

Sedimentation – an increase in sediment falling on a reef can be an important stress factor. Increased sediment might be visible on living coral tissue, and sediment traps of various designs can allow sedimentation to be measured and monitored (e.g., Storlazzi *et al.* 2011).

Suspended Solids – can affect the optical qualities of the water and lead to the accumulation of organic or inorganic material on the reef. As a general rule, suspended solids greater than 4g/L can be considered a stress factor.

Presence/Absence of disease or predation – Although lesions are generally the effect, and not the cause of an insult, the nature of the lesions can help to identify possible causative factors. For example, small, round, white lesions could indicate white disease or fish predation. Closer observations can reveal gouges in the coral skeleton, an indicator of predation.

Occurrence of major physical damage – natural and/or anthropogenic events, e.g., storms, vessel grounding/anchoring, snorkelers.

Absence of certain key non-coral invertebrates – certain invertebrates can be indicators of environmental problems (e.g., the absence of urchins might indicate the presence of toxicants or frequent hypo-salinity events), and can contribute to problems (e.g., the absence of urchins might lead to increased algal overgrowth).

3. Analyzing Data and Evidence from the Case and Elsewhere

Once a conceptual model is built from case specific data (see Fig. 3), it is important to evaluate the data (i.e., evidence) in terms of consistency, credibility, completeness and coherency. This allows evidence to be weighed in terms of supporting one or more lines for causality in the conceptual model (e.g., see Fig. 6). This means:

- The evidence is internally consistent and does not contradict itself.
- The quantity and quality of the evidence is credible.
- The causal relationship(s) exhibits all of the causal characteristics and concurs with precepts of scientific theory.

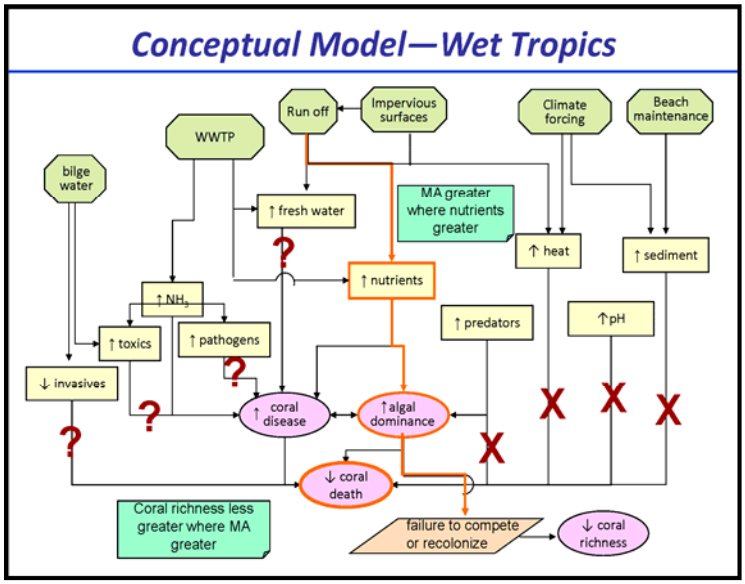


Figure 6 Example of a Conceptual Model showing causal links with some evidence (?), no supportive evidence (X) and the path with the quantity and quality of evidence that is credible (orange line) (note: WWTP—Waste water treatment plant). *Diagram provided by Dr. Susan Cormier.*

This process will allow certain candidate causes to either be rejected or accepted based on the level and credibility of supportive evidence, allowing resources to be focused on investigating

the causes that are most probable based on the evidence. Evaluations that warrant further investigation will trigger Phase III.

PHASE III – CAUSAL INVESTIGATION

The causal investigation of the *Epidemiological Strategy* typically involves collaboration between local resource managers and outside experts that will help to determine which of the candidate causes in the causal web are actually responsible for the observed impairments. The Causal Web formed in Phase II of the investigation is a set of hypotheses created by local resource managers that can then be tested in Phase III to determine the causative agent(s) based on weight of evidence. This methodology can also provide measures of the relative contribution among several contributing agents (or factors). Because problems affecting corals are often multifactorial and may be affected by onshore human-induced factors, strong research-based evidence is often required to effect the necessary changes in government regulations or the public's behavior. Hypotheses generated from Phase II may not be sufficient to effect such change, hence the necessity for a formal, detailed investigation conducted by experts in Phase III. It should be noted that it is not always possible to unequivocally identify a single causative agent, and in this case a weight of evidence approach is a reasonable alternative.

PHASE IV – ENFORCEMENT AND INTERVENTION

Phase IV of the *Epidemiological Strategy* involves corrective action and is based on the results of the causal investigation. The nature of the action will depend on the cause and infraction, the strength of evidence, and the legal, economic and social factors involved in decision making. It is imperative that Phase I surveillance be continued at all sites during the investigation and after the enforcement/intervention takes place so the effects of the corrective actions can be shown. Table 2 provides examples of possible management actions (i.e. adaptive management responses) that could be explored based on the outcome of the Environmental Investigation.

Table 2 Examples of Possible Interventions based on Causal Agent(s) Identification
(Courtesy of Dr. Susan Cormier, USEPA).

Causal Agent	Sources	Adaptive Management Responses
Sediment	Resuspension storms, propellers, beach maintenance, construction, organic particles, dredging and spoil disposal, agriculture	• Restrict beach augmentation • Implement strict fines and controls for run-off • Implement development plan • Impose "windows" for dredging • Protect mangroves • Restrict and reroute boat and vessel traffic

Table 2 continued

Causal Agent	Sources	Options
Nutrients	Atmospheric deposition, waste water from homes and boats, fertilization, distant land sources, fires, spills	• Building permit revision to include composting toilets • Provide grants for composting toilets or non-discharging treatment systems and small business start-ups. • Investigate nutrient sequestration options • Create carbon sequestration reefs as no fishing zones • Improve quality of turtle grass beds
Physical trauma	Storms (increased frequency and severity), boats and anchors, recreational activities	• Create carbon sequestration reefs as no fishing zones • Fund mooring buoy anchor program • Restrict boat access to certain areas. • Establish larger size of limited use areas and sanctuaries
Pathogens	Invasive introductions and opportunistic conditions	• See nutrients • Establish anchor washing and ballast discharge program • Install bilge water treatment systems
Algae	Lack of herbivores, excess nutrients, increased heat	• Create carbon sequestration reefs as no fishing zones • See nutrients
Lack of herbivores	Overfishing, die off (e.g., Diadema)	• Create carbon sequestration reefs as no fishing zones • Reintroduce *Diadema antillarum* and holothurians
Contaminants	Spills, waste, bilge water, cruise and other shipping, atmospheric deposition, agrichemicals, residential and urban run-off, personal care products, waste-water effluents	• See Pathogens • Limit cruise lines to certain ports • See nutrients • Create retention ponds • Use of alternatives products • Improve waste-water treatment • Establish riparian buffers • Develop stormwater management plan

Conclusion

In summary, this document focuses on establishing a coral surveillance program based on an Epidemiological Strategy. It uses *Acropora palmata* as an example, but it is broadly applicable to any species of interest. This strategy involves first collecting baseline data for the population at risk (**Phase I**), focusing on specific health parameters and appropriate trigger points that indicate when to move to a detailed **Phase II** assessment of potential risk factors. Then, by developing and analyzing a conceptual model, the most likely causative factors are identified and a Causal Investigation (**Phase III**) is conducted to identify the specific causative agents. Finally, if warranted, the problem is rectified through management/enforcement (**Phase IV**). Such a program involves researchers, decision makers and enforcement officials at various levels, as outlined in the Causal Analysis Framework (Fig. 7).

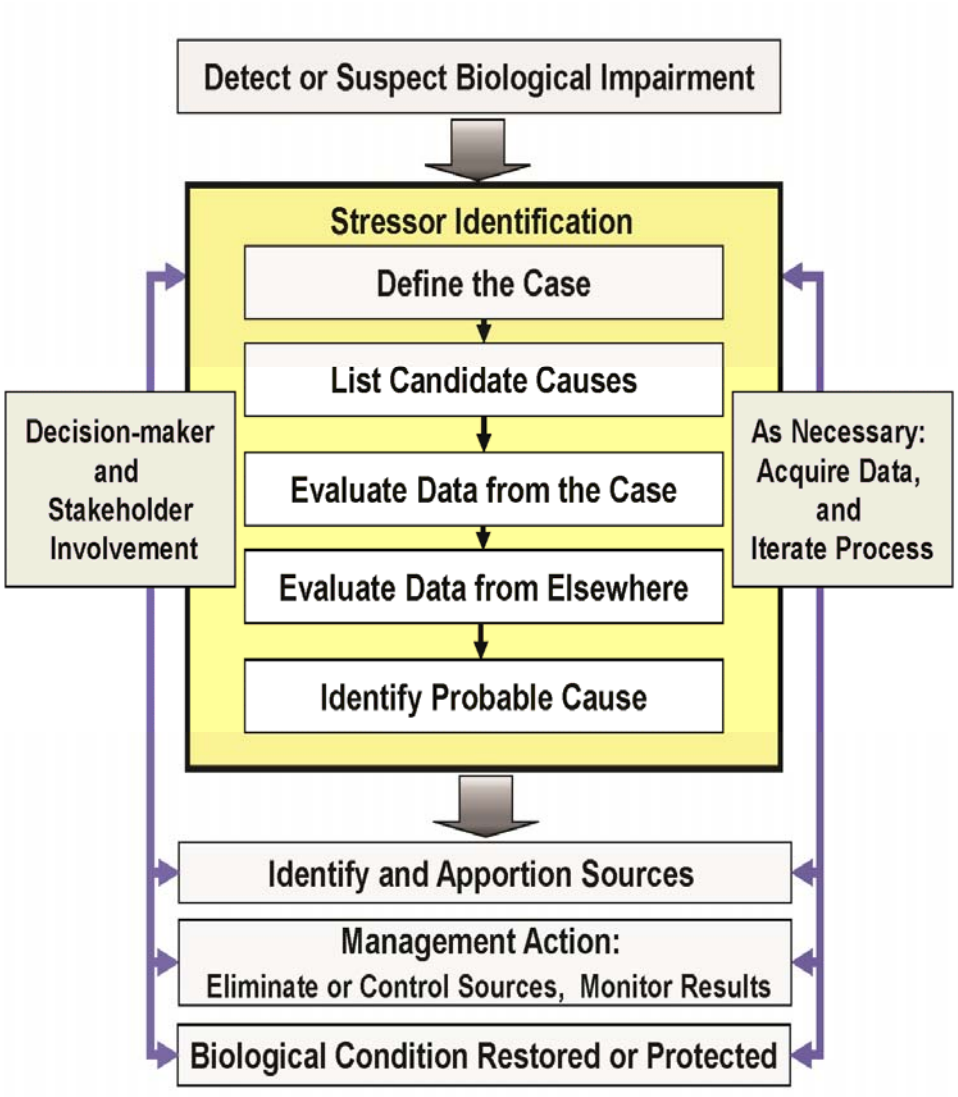


Figure 7. Summary of the Causal Analysis Framework ***(Courtesy of Dr. Susan Cormier, USEPA)***

III. Glossary of Terms

Causality (causation) - the relationship between cause and effect.

Causal (causative) factor (agent) - a factor that causes disease.

Disease - illness; sickness; interruption, cessation or disorder of an organism's normal functions.

Disease in corals - any instance of abnormal pathological effects (e.g. loss of color, visible lesions, microscopic lesions, reproductively sterile) apparent in a coral colony or colonies.

Environmental Forensics Investigation - providing data for a causal factor(s) for use in the courts or public forum.

Epidemiology - study of disease in populations and factors determining its occurrence.

Eutrophication - an increase in the rate of supply of organic matter (nutrients, especially nitrates and phosphate) into an ecosystem, the sources can be artificial or natural and in marine systems often lead to excessive algal growth.

Incidence - the number of new cases of disease that occur over a specified period of time.

Population - all of the organisms that both belong to the same species and live in the same geographical area, for many marine species this may be referred to as a stock, for coral this may be corals co-located on a reef.

Metapopulation - a management term referring to a series of smaller populations that have some level of interaction. Bak & Meesters (1999) defines this as the largest spatial scale of a population which consists of the total grouping of all spatially separated, local populations or subpopulations. Within a metapopulation interactions and exchange between subpopulations are generally low.

Monitoring - routine collection of information, e.g., productivity or distribution or other characteristic of a population.

Morbidity - a diseased condition or state.

Morbidity rate - a general term that includes both incidence and prevalence.

Prevalence - the number of occurrences of disease in a population, usually relating to a particular point in time; it is commonly expressed as the proportion of the population that is affected.

Recruitment - the measure of the number of young individuals (e.g., fish and coral larvae, algae propagules) entering the adult population, in other words, it is the supply of new individuals to a population.

Risk Web or Causal Web - an epidemiological model depicting the multifactorial nature of disease in a complex 'web' or network of interconnected risk and protective factors resulting in various pathways to define routes of risk or causation (for discussion see Wobeser 1994; Krieger 1994; Thrusfield 2007).

Sentinel Colony - a coral colony that is chosen as a prominent representative of a population such that it can be studied closely and regularly in order to detect change in the health of the population.

Stress - reaction of an organism to deleterious forces that tend to disturb its normal equilibrium.

Stressor - stimulus that induces stress.

Subpopulation or local populations - groups of interacting individuals within a species distributed over a range of separate locations (Bak & Meesters 1999).

Syndrome - the aggregate of signs associated with a disease that provides a description of the disease (Thrusfield 2007).

Surveillance - data gathering, recording, analysis, dissemination of information to relevant parties so action can be taken to control disease (Thrusfield 2007).

Syndromic surveillance - involves collecting and analyzing statistical data on health trends—i.e., high frequency of similar symptoms and signs, or surrogate data, e.g., flu medicine sales. Focusing on symptoms/signs rather than confirmed diagnoses provides earlier detection of nonspecific disease (Thrusfield 2007).

Threatened species - defined by the Endangered Species Act as any species which is likely to become an endangered species within the foreseeable future throughout all or a significant portion of its range.

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